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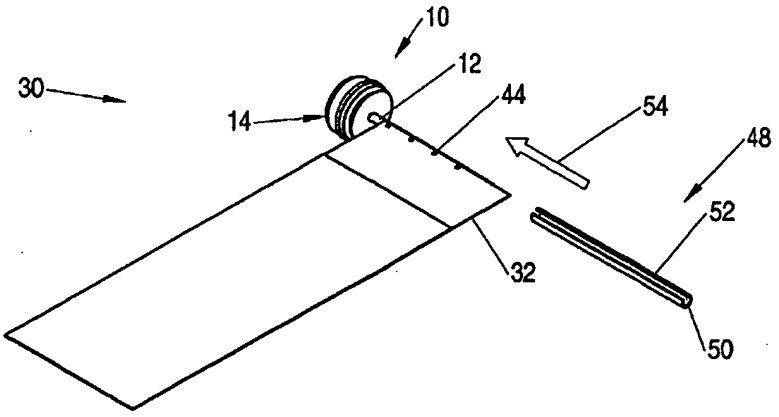

(57) Abstract: An electric storage battery and method of manufacture thereof characterized by a feed through pin (12) which is internally directly physically and electrically connected to an inner end of a positive electrode substrate (32). A C-shaped mandrel (48) extends around the pin and substrate end enabling the pin/mandrel to be used during the manufacturing process as an arbor to facilitate winding layers of a spiral jellyroll electrode assembly. The pin additionally extends from the battery case (101) and in the final product constitutes one of the battery terminals (14) with the battery case comprising the other terminal. The electrolyte is injected through the open end of the case after the end cap is welded to the negative electrode but before sealing the end cap to the case. The electrolyte is preferably injected through the C-shaped mandrel to facilitate and speed filling.

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ELECTRIC STORAGE BATTERY CONSTRUCTION AND METHOD OF MANUFACTURE

TECHNICAL FIELD

This invention relates generally to electric storage batteries and more particularly to a battery construction, and method of manufacture thereof, suitable for use in implantable medical devices.

BACKGROUND

Rechargeable electric storage batteries are commercially available in a wide range of sizes for use in a variety of applications. As battery technology continues to improve, batteries find new applications which impose increasingly stringent specifications relating to physical size and performance. Thus, new technologies have yielded smaller and lighter weight batteries having longer storage lives and higher energy output capabilities enabling them to be used in an increasing range of applications, including medical applications, where, for example, the battery can be used in a medical device which is implanted in a patient's body. Such medical devices can be used to monitor and/or treat various medical conditions.

Batteries for implantable medical devices are subject to very demanding requirements, including long useful life, high power output, low self-discharge rates, compact size, high reliability over a long time period, compatibility with the patient's internal body chemistry, etc. Although various battery chemistries have been tried, lithium ion technology is generally accepted as the preferred chemistry for medical implant applications.

Such electric storage batteries are generally comprised of a tubular metal case enveloping an interior cavity which contains an electrode assembly surrounded by a suitable electrolyte. The electrode assembly generally comprises a plurality of positive electrode, negative electrode, and separator layers which are typically stacked and/or spirally wound to form a jellyroll. The positive electrode is generally formed of a metal substrate having positive active material coated on both faces of the substrate. Similarly, the negative electrode is formed of a metal substrate having negative active material coated on both faces of the substrate. In forming an electrode assembly, separator layers are interleaved between the positive and negative electrode layers to provide electrical isolation.

SUMMARY

The present invention is directed to an electric storage battery incorporating one or more aspects described herein for enhancing battery reliability while minimizing battery size. In addition, the invention is directed to a method for efficiently manufacturing the battery at a relatively low cost.

In accordance with a first significant aspect of the invention, a feedthrough pin is provided which is directly physically and electrically connected to the inner end of an electrode substrate (e.g., positive), as by welding. The pin is used during the manufacturing process as an arbor to facilitate winding the layers to form an electrode assembly jellyroll. Additionally, in the fully manufactured battery, the pin extends through a battery case endcap and functions as one of the battery terminals. The battery case itself generally functions as the other battery terminal.

More particularly, in accordance with an exemplary preferred embodiment, the inner end of the positive electrode substrate is spot welded to the feedthrough pin to form an electrical connection. The substrate, e.g., aluminum, can be very thin, e.g., 0.02 mm, making it difficult to form a strong mechanical connection to the pin, which is preferably constructed of a low electrical resistance, highly corrosion resistant material, e.g., platinum iridium, and can have a diameter on the order of 0.40 mm. In order to mechanically reinforce the pin and secure the pin/substrate connection, a slotted C-shaped mandrel is provided. The mandrel is formed of electrically conductive material, e.g., titanium-6Al-4V, and is fitted around the pin, overlaying the pin/substrate connection. The mandrel is then preferably welded to both the pin and substrate. The mandrel slot defines a keyway for accommodating a drive key which can be driven to rotate the mandrel and pin to wind the electrode assembly layers to form the spiral jellyroll.

In accordance with a further significant aspect of the invention, the outer layer of the jellyroll is particularly configured to minimize the size, i.e., outer radius dimension, of the jellyroll. More particularly, in the exemplary preferred embodiment, the active material is removed from both faces of the negative electrode substrate adjacent its outer end. The thickness of each active material coat can be about 0.04 mm and the thickness of the negative substrate can be about 0.005 mm. By baring the outer end of the negative electrode substrate, it can be adhered directly, e.g., by an appropriate adhesive tape, to the next inner layer to close the jellyroll to while minimizing the roll outer radius dimension.

A battery case in accordance with the invention is comprised of a tubular case body having open first and second ends. The feedthrough pin preferably carries a first endcap

physically secured to, but electrically insulated from, the pin. This first endcap is preferably secured to the case body, as by laser welding, to close the open first end and form a leak free seal. With the jellyroll mounted in the case and the first endcap sealed, the interior cavity can thereafter be filled with electrolyte from the open second end.

In accordance with a still further aspect of the invention, the jellyroll assembly is formed with a flexible electrically conductive tab extending from the negative electrode substrate for electrical connection to the battery case. In accordance with a preferred embodiment, the tab is welded to a second endcap which is in turn welded to the case. The tab is sufficiently flexible to enable the second endcap to close the case body second end after the interior cavity is filled with electrolyte via the open second end. In accordance with an exemplary preferred embodiment, the tab is welded to the inner face of the second endcap such that when the jellyroll is placed in the body, the tab locates the second endcap proximate to the body without obstructing the open second end. After electrolyte filling, the case body is sealed by bending the tab to position the second endcap across the body second end and then laser welding the endcap to the case body.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 is a side view of a feedthrough pin subassembly in accordance with the invention;

Figure 2 is a longitudinal sectional view through the subassembly of Figure 1;

Figure 3 is a plan view of a positive electrode strip utilized in the exemplary preferred electrode assembly in accordance with the invention;

Figure 4 is a side view of the positive electrode strip of Figure 3;

Figure 5 is an enlarged sectional view of the area A of Figure 4 showing the inner end of the positive electrode strip of Figures 3 and 4;

Figure 6 is an isometric view showing the bared inner end of the positive electrode substrate spot welded to the feedthrough pin and configured to receive a C-shaped mandrel thereon;

Figure 7 is an end view showing the C-shaped mandrel being crimped to the pin and electrode;

Figure 8 is an end view showing the C-shaped mandrel mounted on the pin and capturing the positive electrode substrate therebetween;

Figure 9 is an isometric view depicting a drive key accommodated in the slot of the C-shaped mandrel;

Figure 10 is a plan view showing the drive key coupled to a drive motor for rotating the C-shaped mandrel;

Figure 11 is a schematic end view depicting how rotation of the C-shaped mandrel and pin can wind positive electrode, negative electrode, and separator strips to form a spiral jellyroll electrode assembly;

Figure 12 is a plan view of a negative electrode strip utilized in the exemplary preferred electrode assembly in accordance with the invention;

Figure 13 is a side view of the negative electrode strip of Figure 12;

Figure 14 is an enlarged sectional view of the area A of Figure 13 showing the inner end of the negative electrode strip of Figures 12 and 13;

Figure 15 is an enlarged sectional view of the area B of Figure 13 showing the outer end of the negative electrode strip of Figures 11 and 12;

Figure 16 is an isometric view showing that the layers of a spirally wound electrode assembly, i.e., jellyroll;

Figure 17 is a plan view of the negative electrode strip showing the attachment of a flexible electrically conductive tab to the bared outer end of the negative electrode substrate;

Figure 18 is an enlarged sectional view showing how the outer turn of the negative electrode strip is taped to the next inner layer to close the jellyroll to minimize its outer radius dimension;

Figure 19 is an isometric view depicting the jellyroll electrode assembly being inserted into a cylindrical battery case body;

Figure 20 is an isometric view showing a battery case body with the negative electrode tab extending from the open case body;

Figure 21 is an isometric view showing how the negative electrode tab is mechanically and electrically connected to an endcap for sealing the case body second end;

Figure 22 is a side view showing how the negative electrode tab holds the second endcap proximate to the case body second end without obstructing the open second end;

Figure 23 is a front view showing the weld position and the relationship between the various components; and

Figure 24 is an enlarged sectional view of the second end of the battery case showing the endcap in sealed position.

DETAILED DESCRIPTION

Attention is initially directed to Figures 1 and 2 which illustrate a preferred feedthrough pin subassembly 10 utilized in accordance with the present invention. The subassembly 10 is comprised of an elongate pin 12, preferably formed of a solid electrically conductive material, having low electrical resistance and high corrosion resistance such as platinum iridium, preferably 90Pt/10Ir. The pin 12 extends through, and is hermetically sealed to a header 14. The header 14 is comprised of dielectric disks, e.g., ceramic, 16 and 18 which sandwich a glass hollow cylinder 20 therebetween. The glass hollow cylinder is hermetically sealed to the pin 12. The outer surface of the glass hollow cylinder 20 is sealed to the inner surface of an electrically conductive hollow member 22, e.g., titanium-6Al-4V. As will be seen hereinafter, the conductive hollow material 22 functions as a battery case endcap in the final product to be described hereinafter.

Attention is now directed to Figures 3, 4, and 5 which illustrate a preferred positive electrode strip 30 which is utilized in the fabrication of a preferred spirally wound jellyroll electrode assembly in accordance with the present invention. The positive electrode strip 30 is comprised of a metal substrate 32 formed, for example, of aluminum. Positive electrode active material 34, 36 is deposited, respectively on the upper and lower faces 38 and 40 of the substrate 32. Note in Figures 3, 4, and 5 that the right end of the substrate 32 is bare, i.e. devoid of positive active material on both the upper and lower faces 38, 40.

It is to be pointed out that exemplary dimensions are depicted in Figures 1-5 and other figures herein. These exemplary dimensions are provided primarily to convey an order of magnitude to the reader to facilitate an understanding of the text and drawings. Although the indicated dimensions accurately reflect one exemplary embodiment of the invention, it should be appreciated that the invention can be practiced utilizing components having significantly different dimensions.

Figure 6 depicts an early process step for manufacturing a battery in accordance with the invention utilizing the pin subassembly 10 (Figures 1, 2) and the positive electrode strip 30 (Figures 3-5). A topside electrode insulator (not shown), which may comprise a thin disk of DuPont Kapton® polyimide film, is slipped onto the pin 12 adjacent the header 14. In accordance with the present invention, the bare end of the electrode strip substrate 32 is electrically connected to the pin 12 preferably by resistance spot welding, shown at 44. Alternatively, substrate 32 may be ultrasonically welded to the pin 12. The thinness, e.g. point 0.02 mm of the substrate 32, makes it very difficult to form a strong mechanical connection

between the substrate and the pin 12. Accordingly, in accordance with a significant aspect of the present invention, an elongate C-shaped mandrel 48 is provided to mechanically reinforce the pin 12 and secure the substrate 32 thereto.

The mandrel 48 preferably comprises an elongate titanium or titanium alloy such as Ti-6Al-4V tube 50 having a longitudinal slot 52 extending along the length thereof. The arrow 54 in Figure 6 depicts how the mandrel 48 is slid over the pin 12 and substrate 32, preferably overlaying the line of spot welds 44. The mandrel 48, pin 12, and substrate 32 are then preferably welded together, such as by resistance spot welding or by ultrasonic welding. Alternatively, the mandrel 48 may be crimped onto the pin 12 at least partially closing the "C" to create a strong mechanical connection. In the case of forming only a mechanical connection and not necessarily a gas-tight electrical connection between the mandrel 48 and the pin and substrate, the mandrel material is preferably made of a material that will not lead to electrolysis. When used with electrolytes that tend to contain hydrofluoric acid, the mandrel is preferably made of 304, 314, or 316 stainless steels or aluminum or an alloy thereof chosen for its compatibility with the other materials. Figure 7 is an end view showing the step of crimping the mandrel 48 to the pin 12 and substrate 32. Supporting die 126 is used to support the mandrel 48 and crimping dies 124 and 125 are used to deform the edges of the mandrel 48 to bring them closer together and mechanically connect the mandrel 48 to the pin 12 and substrate 32. By crimping in the direction of arrows 127 and 128, a strong connection is formed without damaging the thin electrode or disturbing the electrical connection between the pin and the electrode.

Figure 8 is an end view showing the slotted mandrel 48 on the pin 12 with the substrate 32 extending tangentially to the pin 12 and terminating adjacent the interior surface of the mandrel tube 50. The tube 50 is preferably sufficiently long so as to extend beyond the free end of the pin 12. As depicted in Figure 9, this enables a drive key 56 to extend into the mandrel slot 52.

Figure 10 schematically depicts a drive motor 60 for driving the drive key 56 extending into mandrel slot 52. With the pin subassembly header 14 supported for rotation (not shown), energization of the motor 60 will orbit the key drive 56 to rotate the mandrel 48 and subassembly 10 around their common longitudinal axes. The rotation of the mandrel 48 and subassembly 10 is employed to form a jellyroll electrode assembly in accordance with the present invention.

More particularly, Figure 11 depicts how a jellyroll electrode assembly is formed in accordance with the present invention. The bare end of the substrate 32 of the positive electrode

strip 30 is electrically connected to the pin 12 as previously described. The conductive mandrel 48 contains the pin 12 and bare substrate end, being welded to both as previously described. A strip of insulating separator material 64 extending from opposite directions is introduced between the mandrel 48 and positive electrode substrate 32, as shown. A negative electrode strip 70 is then introduced between the portions of the separator material extending outwardly from mandrel 48.

The preferred exemplary negative electrode strip 70 is depicted in Figures 12-15. The negative electrode strip 70 is comprised of a substrate 72, e.g. titanium, having negative active material formed on respective faces of the substrate. More particularly, note in Figure 14 that negative active material 74 is deposited on the substrate upper surface 76 and negative active material 78 is deposited on the substrate lower surface 80. Figure 14 depicts the preferred configuration of the inner end 82 of the negative electrode strip 70 shown at the left of Figures 12 and 13. Figure 15 depicts the configuration of the outer end 83 of the negative electrode strip 70 shown at the right side of Figures 12 and 13.

Note in Figure 14 that one face of the substrate inner end 82 is bared. This configuration can also be noted in Figure 11 which shows how the negative substrate inner end 82 is inserted between turns of the separator strip 64. After the strip 70 has been inserted as depicted in Figure 11, the aforementioned drive motor 60 is energized to rotate pin 12 and mandrel 48, via drive key 56, in a counterclockwise direction, as viewed in Figure 11. Rotation of pin 12 and mandrel 48 functions to wind positive electrode strip 30, separator strip 64, and negative electrode strip 70, into the spiral jellyroll assembly 84, depicted in Figure 16. The assembly 84 is comprised of multiple layers of strip material so that a cross section through the assembly 84 would reveal a sequence of layers in the form pos/sep/neg/sep/pos/sep/neg/..., etc.

Figure 15 depicts a preferred configuration of the outer end 83 of the negative electrode strip 70. Note that the outer end 88 of the substrate 72 is bare on both its top and bottom faces. These bared portions may be provided by masking the substrate prior to coating, by scraping active material after coating, or by other means well known in the art. Additionally, as shown in Figure 17, a flexible metal tab 90 is welded crosswise to the substrate 72 so as to extend beyond edge 92. More particularly, note that portion 94 of tab 90 is cantilevered beyond edge 92 of negative electrode strip 70. This tab portion, as will be described hereinafter, is utilized to mechanically and electrically connect to an endcap for closing a battery case.

Attention is now called to Figure 18, which illustrates a preferred technique for closing the jellyroll assembly 84. That is, the bare end 88 of the negative electrode substrate 72

extending beyond the negative active material coat 78 is draped over the next inner layer of the jellyroll assembly 84. The end 88 can then be secured to the next inner layer, e.g., by appropriate adhesive tape 96. One such suitable adhesive tape is DuPont Kapton® polyimide tape. It is important to note that the outer end configuration 88 of the negative electrode strip 70 enables the outer radius dimension of the jellyroll assembly 84 to be minimized as shown in Figure 18. More particularly, by baring the substrate 72 beyond the active material 78, the tape 96 is able to secure the substrate end without adding any radial dimension to the jellyroll assembly. In other words, if the outer end of the substrate were not sufficiently bared, then the tape 96 would need to extend over the active material and thus add to the outer radius dimension of the jellyroll 84. Furthermore, the bare substrate 72 is more flexible than the substrate coated with active material 78 and conforms more readily to the jellyroll assembly 84, making it easier to adhere it to the surface of the jellyroll. These space savings, although seemingly small, can be clinically important in certain medical applications. It should be noted that the electrode need only be bared at an end portion long enough to accommodate the tape 96, as shown in Figure 18. Because the uncoated substrate does not function as an electrode, it would waste space in the battery to bare any more than necessary to accommodate the tape. In a preferred embodiment, the length of uncoated substrate is between 1 and 8 mm, and more preferably about 2 mm. In some embodiments, as illustrated, the outer layer is an electrode layer, and the tape is applied to the outer electrode layer. However, in other embodiments, to facilitate insertion of the electrode assembly into the battery case, the outer layer is a separator layer to keep the outer electrode layer from sticking to the inside of the battery case during insertion. This configuration is particularly useful in a battery when the outer electrode layer is lithium metal, which tends to grab onto the case material during insertion.

Figure 19 depicts the completed jellyroll assembly 84 and shows the cantilevered tab portion 94 prior to insertion into a battery case body 100. The case body 100 is depicted as comprising a cylindrical metal tube 101 having an open first end104 and open second end 106. In a preferred embodiment in which small volume and weight are desirable, the case body 100 comprises Ti-6Al-4V alloy or stainless steel, and is less than 0.25 mm (0.010 inches) thick, and more preferably less than 0.125 mm (0.005 inches) thick, and most preferably less than 0.076 mm (0.003 inches) thick. Arrow 107 represents how the jellyroll assembly 84 is inserted into the cylindrical tube 101. Figure 20 depicts the jellyroll assembly 84 within the tube 101 with the cantilevered negative electrode tab 94 extending from the case open second end 106. The case open first end 104 is closed by the aforementioned header 14 of the pin subassembly 10

shown in Figures 1 and 2. More particularly, note that the metal hollow member 22 is configured to define a reduced diameter portion 108 and shoulder 110. The reduced diameter portion 108 is dimensioned to fit into the open end 104 of the cylindrical tube 101 essentially contiguous with the tube's inner wall surface. The shoulder 110 of the hollow member 22 engages the end of the case tube 101. This enables the surfaces of the reduced diameter portion 108 and shoulder 110 to be laser welded to the end of the case 100 to achieve a hermetic seal.

Attention is now directed to Figures 21-24, which depict the tab 94 extending from the second open end 106 of the case tube 101. Note that the tab 94 extends longitudinally from the body close to the case tube adjacent to tube's inner wall surface. In accordance with a preferred embodiment of the invention, the tab 94 is welded at 110 to the inner face 112 of a circular second endcap 114. In accordance with a preferred embodiment, the tab 94 is sufficiently long to locate the weld 110 beyond the center point of the circular endcap 114. More particularly, note in Figures 21-24 that by locating the weld 110 displaced from the center of the cap 114, the tab 94 can conveniently support the endcap 114 in a vertical orientation as depicted in Figure 22 misaligned with respect to the open end 106. This end cap position approximately perpendicular to the end 122 of the case 100 is a first bias position wherein the end cap advantageously tends to remain in that orientation with the case end open prior to filling. To further describe the relationship between the weld location and the various components, Figure 23 shows a front view with various dimensions. L represents the length from the weld 110 to the top of the case 100 as measured parallel to the edge of the case. R is the radius of the end cap 114. For the preferred geometry, $L \leq 2R$. Weld 110 is preferably made above the center point 111 of the end cap 114. Preferably, the end cap 114 overlaps the case 100 by approximately R/2. By configuring the tab 94 and weld 110 as indicated, the endcap 114 can be supported so that it does not obstruct the open end 106, thereby facilitating electrolyte filling of the case interior cavity via open end 106. A filling needle or nozzle can be placed through open end 106 to fill the case. This obviates the need for a separate electrolyte fill port, thereby reducing the number of components and number of seals to be made, thus reducing cost and improving reliability. Furthermore, for small medical batteries, the end caps would be very small to have fill ports therein. In a preferred embodiment in which the case wall is very thin, for example, about 0.002 inches (about 50 μm), providing a fill port in the side wall of the case would be impractical. Even in the case of larger devices where space is less critical and the wall is more substantial, providing a fill port in the side of the case would mean the electrolyte would have a very long path length to wet the jellyroll. Note that while the case could be filled with electrolyte

prior to welding tab 94 to endcap 114, it would be difficult and messy to do so. Therefore, it is advantageous to configure the tab 94 and weld 110 as described to allow the weld to be made prior to filling.

Preferably before filling, a bottomside electrode insulator (not shown), which may comprise a thin disk of DuPont Kapton® polyimide film, is installed into the case between the rolled electrode assembly and the still open end of the battery case.

In a preferred filling method, there is a channel of air between the pin and the crimped or welded C-shaped mandrel, which is used as a conduit for quickly delivering the electrolyte to the far end of the battery and to the inside edges of the electrodes within the jellyroll. Filling from the far end of the battery prevents pockets of air from being trapped, which could form a barrier to further filling. This facilitates and speeds the filling process, ensuring that electrolyte wets the entire battery.

Thereafter, the flexible tab 94 can be bent to the configuration depicted in Figure 24. Note that the endcap 114 is configured similarly to header hollow member 22 and includes a reduced diameter portion 118 and a shoulder 120. The reduced diameter portion snugly fits against the inner surface of the wall of tube 101 with the endcap shoulder 120 bearing against the end 122 of the cylindrical case 100. The relatively long length of the tab 94 extending beyond the center point of the endcap surface 112 minimizes any axial force which might be exerted by the tab portion 94 tending to longitudinally displace the endcap 114. The end cap position covering the end 122 of the case 100 is a second bias position wherein the end cap advantageously tends to remain in that orientation prior to welding. With the endcap in place, it can then be readily welded to the case wall 101 to hermetically seal the battery. With tab 90 welded to negative substrate 72 and with the negative electrode strip 70 as the outermost layer of the jellyroll, the endcap 114 becomes negative. In turn, welding the endcap 114 to the case 100 renders the case negative.

The following examples describe electric storage batteries and methods for making them according to the present invention, and set forth the best mode contemplated by the inventors of carrying out the matter, but are not to be construed as limiting. For example, alternative methods for preparing the negative electrode could be used, such as that described in copending patent application Serial Number 10/264,870, filed October 3, 2002, which is assigned to the assignee of the present invention and incorporated herein by reference in its entirety. Furthermore, although the example given is for lithium ion rechargeable and lithium primary batteries, the

present invention is not limited to lithium chemistries, and may be embodied in batteries using other chemistries.

EXAMPLE 1: Rechargeable Battery

The negative electrode was prepared by combining a mixed-shape graphite with poly(vinylidene) fluoride (PVdF) in a ratio of 85:15 in N-methyl-pyrrolidinone (NMP), then mixing to form a slurry. A 5-μm titanium foil substrate was coated with the slurry, then dried by evaporating the NMP off using heat, then compressed to a thickness of about 79 μm. Portions of negative active material were scraped off to leave certain portions of the negative substrate uncoated, as described above.

A positive active material slurry was prepared by mixing $LiCo_{0.15}Ni_{0.8}Al_{0.05}O_2$, poly(vinylidene) fluoride (PVDF) binder, graphite, acetylene black, and NMP. The slurry was coated onto both sides of a 20-μm thick aluminum foil. The positive electrode was compressed to a final total thickness of about 87 μm. Portions of positive active material were scraped off to leave certain portions of the positive substrate uncoated, as described above.

The 8.59 mm x 29.14 mm-negative electrode and 7.8 mm x 23.74 mm-positive electrode were then spirally wound with a layer of polyethylene separator between them, using the winding technique described above to form a jellyroll electrode assembly. Adhesive tape was applied to close the jellyroll in the manner described above. The jellyroll was inserted into a circular cylindrical Ti-6Al-4V 0.05-mm thick case having a diameter of about 2.9 and a height of about 11.8 mm, for a total external volume of about 0.08 cm^3. An electrolyte comprising $LiPF_6$ in a mixture of ethylene carbonate (EC) and diethyl carbonate (DEC) was delivered to the electrode assembly using the C-shaped mandrel as a conduit, as described above. The end of the battery case was closed, using the technique described above, hermetically sealing the case.

The battery produced in this example was suitable for implanting in a human body, being hermetically sealed and very small. In fact, due to its small diameter and circular cylindrical shape, this rechargeable battery can be used in a device inserted into the body using a syringe-like device having a needle. Preferably, for this method of implantation, the diameter of the battery is less than 3 mm. The volume is preferably less than 1 cm^3, more preferably less than 0.5 cm^3, and most preferably less than 0.1 cm^3. Using one or a combination of the various techniques described herein allows a spirally wound jellyroll-type electrode assembly to be fit into a very small battery case of a volume not seen in the prior art. The very small battery of this example is particularly suitable for applications requiring excellent cycleability, operating at low current, such as diagnostic or other low energy applications.

For a battery to be useful at a given rate, the capacity should be higher than 70% of its capacity at a very low rate, such as 0.2C. For the cell of this example, 3 mA = 1C. As shown in the table below, two batteries produced according to this example were tested for their rate capability at 37°C, charging to 4.0 V at 1.5 mA, using a 0.15 mA cutoff, and discharging at 0.6, 1.5, 3.0, 6, 9, 15, and 30 mA to 2.7 V. The batteries were found to meet the greater than 70% capacity criterion for all rates up to and including 5C. In fact, they were found to have greater than 80% capacity at rates up to 5C, greater than 90% for rates of up to 3C, and greater than 95% for rates up to 1C.

Discharge rate (mA)	Discharge rate (C)	Cell 1 % Capacity	Cell 2 % Capacity	Average % Capacity
0.6	0.2	100	100	100
1.5	0.5	98.1	97.8	97.9
3.0	1	95.9	95.5	95.7
6	2	93.2	92.6	92.9
9	3	90.3	89.6	90.0
15	5	80.8	80.7	80.8
30	10	45.1	47.9	46.5

Table Capacity at various rates expressed as % of capacity at a rate of 0.2C.

EXAMPLE 2: Primary Battery

The negative electrode was prepared by laminating 30 μm lithium foil onto both sides of 5 μm copper foil, for a total thickness of about 65 μm, leaving certain portions of the negative substrate free of lithium to facilitate connections and allow room for adhesive tape, as described above.

A positive active material slurry was prepared by mixing CF_x, polytetrafluoroethylene (PTFE), carbon black, and carboxy methylcellulose (CMC) in a ratio of 80:4:10:6. The slurry was coated onto both sides of a 20-μm thick aluminum foil. The positive electrode was compressed to a final total thickness of about 108 μm. Portions of positive active material were scraped off to leave certain portions of the positive substrate uncoated, as described above.

The 21 mm x 22 mm-negative electrode and 20 mm x 17 mm-positive electrode were then spirally wound with a layer of 25 μm polypropylene separator between them, using the winding technique described above to form a jellyroll electrode assembly. Because lithium sticks to the case material during insertion, the outer layer of the electrode assembly was a layer

of the separator material to facilitate introduction of the jellyroll into the case. Adhesive tape was applied to close the jellyroll in the manner described above. The jellyroll was inserted into a circular cylindrical stainless steel 0.1-mm thick case having a diameter of about 2.9 and a height of about 26 mm, for a total external volume of about 0.17 cm^3. An electrolyte comprising $LiPF_6$ in a mixture of ethylene carbonate (EC) and diethyl carbonate (DEC) was delivered to the electrode assembly, but without using the C-shaped mandrel as a conduit in the above-described manner. The end of the battery case was closed, using the technique described above, hermetically sealing the case.

The battery produced in this example was suitable for implanting in a human body, being hermetically sealed and very small. Although its volume and length were approximately double that of the rechargeable battery described in Example 1, due to its small diameter and circular cylindrical shape, this primary battery also can be used in a device inserted into the body using a syringe-like device having a needle. Using one or a combination of the various techniques described herein allows a spirally wound jellyroll-type electrode assembly to be fit into a very small battery case of a volume not seen in the prior art. The very small primary battery of this example is particularly suitable for applications for which it is important to have less of a voltage drop during pulsing, that do not require rechargeability.

From the foregoing, it should now be appreciated that an electric storage battery construction and method of manufacture have been described herein particularly suited for manufacturing very small, highly reliable batteries suitable for use in implantable medical devices. Although a particular preferred embodiment has been described herein and exemplary dimensions have been mentioned, it should be understood that many variations and modifications may occur to those skilled in the art falling within the spirit of the invention and the intended scope of the appended claims.

CLAIMS

We claim:

1. An electric storage battery including:

a case comprising a peripheral wall defining an interior volume; and

an electrode assembly mounted in said interior volume, said electrode assembly including:

an electrically conductive elongate pin; and

first and second opposite polarity electrode strips wound together to form a spiral roll, each electrode strip having inner and outer ends, wherein said first electrode strip is electrically coupled to said pin at said inner end; and

a hollow elongate mandrel closely fitted around said pin for mechanically reinforcing said pin.

2. The battery of claim 1 wherein said pin extends exteriorly of said case peripheral wall to function as a first battery terminal.

3. The battery of claim 1 wherein said mandrel is electrically coupled to said pin.

4. The battery of claim 1 wherein said first electrode strip inner end is directly connected to said pin by at least one weld.

5. The battery of claim 1 wherein said pin consists of a PtIr alloy.

6. The battery of claim 1 further comprising a first end cap mounted on said pin, said first end cap including an electrical insulator; and wherein

said pin extends through and is hermetically sealed to said end cap electrical insulator.

7. The battery of claim 1 wherein said mandrel defines an elongate slot; and wherein said first electrode strip extends through said mandrel slot.

8. The battery of claim 1 wherein said mandrel is welded to said pin.

9. The battery of claim 1 wherein said mandrel comprises titanium or an alloy thereof.

10. An electric storage battery made by the acts of:
providing an electrically conductive elongate pin having inner and outer ends;
providing a first polarity electrode strip;
providing a second polarity electrode strip;
electrically connecting a first end of the first polarity electrode strip to the pin proximate to the pin inner end;
mounting a reinforcing mandrel on the pin; and
winding together the first polarity electrode strip and the second polarity electrode strip to form a spiral roll having at least a portion of the pin within the spiral roll.

11. The battery of claim 10 wherein said acts further include the act of mounting the spiral roll in a case with the pin outer end extending exteriorly of the case to form a first battery terminal.

12. The battery of claim 10 wherein said acts further include the act of electrically coupling the reinforcing mandrel to the pin.

13. The battery of claim 10 wherein said act of winding together the first polarity electrode strip and the second polarity electrode strip comprises rotating the pin.

14. The battery of claim 10 wherein said act of providing an electrically conductive elongate pin includes a act of:
forming an end cap including an insulating member on the pin hermetically sealed thereto and positioned proximate to but spaced from the pin outer end.

15. The battery of claim 14 wherein said acts further include a act of mounting a conductive member around the insulating member; and
electrically connecting the conductive member to the case.

16. The battery of claim 10 wherein said acts further include a act of welding the reinforcing mandrel to the pin.

17. The battery of claim 1 wherein the mandrel comprises a tube having a slot therein and wherein said winding act further includes the acts of:
inserting a drive key into the slot; and
orbiting the drive key to rotate the mandrel and pin.

18. The battery of claim 1 wherein the mounted mandrel comprises a channel and wherein said acts further include a act of injecting electrolyte through the channel.

19. A method of constructing an electric storage battery including:
providing an electrically conductive elongate pin having inner and outer ends;
providing a first polarity electrode strip;
providing a second polarity electrode strip;
electrically connecting a first end of said first polarity electrode strip to said pin proximate to said pin inner end;
mounting a reinforcing mandrel on the pin;
winding together said first polarity electrode strip and said second polarity electrode strip to form a spiral roll having at least a portion of the pin within the spiral roll.

20. The method of claim 19 and further including the act of:
mounting said spiral roll in a case with said pin outer end extending exteriorly of said case to form a first battery terminal.

21. The method of claim 19 and further including the act of:
electrically coupling the reinforcing mandrel to the pin.

22. The method of claim 19 wherein said act of winding together the first polarity electrode strip and the second polarity electrode strip comprises rotating the pin.

23. The method of claim 19 wherein said act of providing said electrically conductive elongate pin includes a act of:
forming an end cap including an insulating member on said pin hermetically sealed thereto and positioned proximate to but spaced from said pin outer end.

24. The method of claim 23 including the further act of mounting a conductive member around said insulating member; and
electrically connecting said conductive member to said case.

25. The method of claim 19 including a further act of welding the reinforcing mandrel to the pin.

26. The method of claim 19 said act of mounting a reinforcing mandrel comprises mounting a mandrel comprising a tube having a slot therein; and wherein said winding act further includes the acts of:
inserting a drive key into the slot; and
orbiting the drive key to rotate the mandrel and pin.

27. The method of claim 19 wherein the said act of mounting a reinforcing mandrel comprises providing a channel and wherein said acts further include a act of injecting electrolyte through the channel.

28. An electrode assembly including:
an electrically conductive, elongate pin;
an elongate reinforcing mandrel mounted on at least a portion of said pin; and
a spiral roll comprising first and second opposite polarity electrode strips and at least one separator strip separating said electrode strips mounted on said pin, wherein one of said electrode strips is electrically coupled to said pin.

29. The electrode assembly of claim 28 wherein said mandrel is C-shaped and defines a longitudinal slot; and wherein
an inner end of said first electrode strip extends through said mandrel slot and is electrically connected to said pin.

30. The electrode assembly of claim 28 wherein said pin comprises a portion extending beyond said spiral roll to form a battery terminal.

31. The electrode assembly of claim 28 wherein said mandrel is crimped onto said pin.

32. The electrode assembly of claim 28 wherein the mounted mandrel has a channel through which electrolyte can be injected.

33. An electrode assembly made by the acts of:
providing an electrically conductive, elongate pin;
providing a first polarity electrode strip;
providing a second polarity electrode strip;
electrically connecting a first end of the first polarity electrode strip to the pin;
mounting a reinforcing mandrel on the pin; and
winding together the first polarity electrode strip and the second polarity electrode strip to form a spiral roll having at least a portion of the pin and the mandrel interior to the spiral roll.

34. The assembly of claim 33 wherein said acts further include a act of crimping the reinforcing mandrel to the pin.

35. The assembly of claim 33 wherein said acts further include a act of welding the reinforcing mandrel to the pin.

36. The assembly of claim 33 wherein said act of winding together the first polarity electrode strip and the second polarity electrode strip comprises rotating the pin and the mandrel.

37. The assembly of claim 33 wherein said act of winding together the first polarity electrode strip and the second polarity electrode strip to form a spiral roll comprises leaving a portion of the pin extending beyond the spiral roll to form a battery terminal.

38. A method of constructing an electric storage battery including:
providing an electrically conductive, elongate pin;
providing a first polarity electrode strip;
providing a second polarity electrode strip;
electrically connecting a first end of said first polarity electrode strip to said pin;
mounting a reinforcing mandrel on said pin; and
winding together the first polarity electrode strip and the second polarity electrode strip to form a spiral roll.

39. The method of claim 38 including the further act of crimping the reinforcing mandrel to the pin.

40. The method of claim 38 including the further act of welding the reinforcing mandrel to the pin.

41. The method of claim 38 wherein said act of winding together the first polarity electrode strip and the second polarity electrode strip comprises rotating the pin and the mandrel.

42. The method of claim 38 wherein said act of winding together the first polarity electrode strip and the second polarity electrode strip to form a spiral roll comprises leaving a portion of the pin extending beyond the spiral roll to form a battery terminal.

43. An electric storage battery comprising:

an electrically conductive case sealed by first and second end caps;

an electrically conductive terminal pin extending through said first end cap and electrically insulated from said case;

an electrode assembly disposed within said case and comprising first and second opposite polarity electrodes separated by separators wherein said first electrode is electrically coupled to said pin;

a flexible conductive tab electrically coupled to said second electrode proximate a first location at the seal formed between said second end cap and said case;

wherein said second end cap has a center and wherein said second end cap has a width from said first location to a second location at the seal formed between said second end cap and said case measured along a line through said center; and

said tab electrically connected to said second end cap at a third location between said second location and said center of said second end cap.

44. The battery of claim 43 wherein said case has no separate fill hole.

45. The battery of claim 43 wherein said second end cap is welded to said tab flat against an inner face of said second end cap.

46. The battery of claim 43 wherein said second end cap is circular and wherein said width is a diameter.

47. An electric storage battery made by the acts of:

providing a case comprising a peripheral wall of electrically conductive material defining an interior volume and having first and second wall openings communicating with the interior volume;

providing an electrically conductive terminal pin extending through a first end cap and electrically insulated from the case

providing an electrode assembly comprising first and second opposite polarity electrodes

electrically connecting the first electrode to the pin;

forming a flexible conductive tab extending beyond a second edge of the electrode assembly and electrically connected to the second electrode ;

mounting the electrode assembly in the interior volume with the pin extending out through the first wall opening and the tab extending out through the second wall opening;

mounting the first end cap to seal the first wall opening;

providing a second end cap of electrically conductive material; and

fastening the second end cap to the tab in a manner to provide an electrical connection therebetween.

48. The electric storage battery of claim 47 wherein said acts further include a further act of depositing electrolyte into the case through the second wall opening following said act of fastening the second end cap to the tab.

49. The electric storage battery of claim 47 wherein said act of fastening the second end cap to the tab includes welding the tab flat against an inner face of the second end cap.

50. The electric storage battery of claim 49 including the further act of mounting the end cap in the second wall opening to seal the second wall opening.

51. A method of constructing an electric storage battery including:

providing a case comprising a peripheral wall of electrically conductive material defining an interior volume and having first and second wall openings communicating with the interior volume;

providing an electrically conductive terminal pin extending through a first end cap and electrically insulated from the case

providing an electrode assembly comprising first and second opposite polarity electrodes wherein the first electrode is electrically connected to the pin;

forming a flexible conductive tab extending beyond a second edge of the electrode assembly and electrically connected to the second electrode ;

mounting the electrode assembly in the interior volume with the pin extending out through the first wall opening and the tab extending out through the second wall opening;

mounting the first end cap to seal the first wall opening;

providing a second end cap of electrically conductive material; and

fastening the second end cap to the tab in a manner to provide a mechanical and electrical connection therebetween.

52. The method of claim 51 including a further act of depositing electrolyte into the case through the second wall opening after said act of fastening the second end cap to the tab.

53. The method of claim 51 wherein said act of fastening the second end cap to the tab includes welding the tab flat against an inner face of the second end cap.

54. The method of claim 53 including the further act of mounting the end cap in the second wall opening to seal the second wall opening.

55. An electric storage battery comprising:

an electrically conductive case hermetically sealed by first and second end caps, wherein said case has no separate fill holes and wherein said first and second end caps have no separate fill holes;

an electrically conductive terminal pin extending through said first end cap and electrically insulated from said case;

an electrode assembly disposed within said case and comprising first and second opposite polarity electrodes separated by separators wherein said first electrode is electrically coupled to said pin; and

a flexible conductive tab electrically coupled to said second electrode and to said second end cap.

56. An electric storage battery made by the acts of:

providing a case comprising a peripheral wall of electrically conductive material defining an interior volume and having first and second wall openings communicating with the interior volume;

providing an electrically conductive terminal pin extending through the first end cap and electrically insulated from the case;

providing an electrode assembly comprising first and second opposite polarity electrodes

electrically coupling the first electrode to the pin;

mounting the electrode assembly in the interior volume with the pin extending out through the first wall opening;

mounting the first end cap to seal the first wall opening;

providing a second end cap of electrically conductive material; and

electrically coupling the second electrode to the second end cap;

depositing electrolyte into the case through the second wall opening; and

mounting the end cap in the second wall opening to seal the second wall opening.

57. The electric storage battery of claim 56 wherein the act of electrically coupling the second electrode to the second end cap precedes the act of depositing electrolyte into the case through the second wall opening.

58. A method of constructing an electric storage battery including:

providing a case comprising a peripheral wall of electrically conductive material defining an interior volume and having first and second wall openings communicating with the interior volume;

providing an electrically conductive terminal pin extending through the first end cap and electrically insulated from the case;

providing an electrode assembly comprising first and second opposite polarity electrodes

electrically coupling the first electrode to the pin;

mounting the electrode assembly in the interior volume with the pin extending out through the first wall opening;

mounting the first end cap to seal the first wall opening;

providing a second end cap of electrically conductive material; and

electrically coupling the second electrode to the second end cap;

depositing electrolyte into the case through the second wall opening; and

mounting the end cap in the second wall opening to seal the second wall opening.

59. The method of claim 58 wherein the act of electrically coupling the second electrode to the second end cap precedes the act of depositing electrolyte into the case through the second wall opening.

60. A hermetically sealable electric storage battery comprising:

a case having an open end;

a first electrically conductive terminal electrically insulated from said case;

an electrode assembly disposed within said case and comprising first and second opposite polarity electrodes separated by separators wherein said first electrode is electrically coupled to said first terminal;

a flexible conductive tab electrically coupled to said second electrode proximate a first location at said case open end;

said tab electrically connected to said end cap at a second location whereby said end cap has a first bias position tending to keep said case open end open and a second bias position tending to close said case open end.

61. The battery of claim 60 wherein said first bias position orients said end cap approximately perpendicular to said open end.

62. The battery of claim 60 wherein said second end cap is welded to said tab flat against an inner face of said second end cap.

63. The battery of claim 60 wherein:

said end cap is circular and has a radius R;

the distance from said second location to said case open end is a length L; and

$L \leq 2R$.

64. The battery of claim 63 wherein said second location is above the center of said end cap in said first bias position.

65. The battery of claim 63 wherein said end cap overlaps the case by approximately R/2 in said second bias position.

66. An electric storage battery including:

a case comprising a peripheral wall defining an interior volume and an exterior volume of less than 1 cm^3; and

an electrode assembly mounted in said interior volume, said electrode assembly including first and second opposite polarity electrode strips wound together to form a spiral roll.

67. The electric storage battery of claim 66 wherein said external volume is less than 0.5 cm^3.

68. The electric storage battery of claim 66 wherein said external volume is less than 0.1 cm^3.

69. The electric storage battery of any of claims 66 - 68 wherein said case is circularly cylindrical.

70. The electric storage battery of any of claims 66 - 69 wherein said case has a diameter less than 3 mm.

71. The electric storage battery of any of claims 66 - 70 wherein said case is hermetically sealed.

72. The electric storage battery of any of claims 66 - 71 wherein said battery is rechargeable.

73. The electric storage battery of any of claims 66 - 71 wherein said battery is a primary battery.

74. The electric storage battery of any of claims 66 - 73 wherein said battery is a lithium or lithium ion battery.

75. The electric storage battery of any of claims 66 - 74 wherein said electrode assembly further includes:

an electrically conductive elongate pin; and

wherein each electrode strip has inner and outer ends, wherein said first electrode strip is electrically coupled to said pin at said inner end.

76. The electric storage battery of claim 75 wherein said electrode assembly further includes a hollow elongate mandrel closely fitted around said pin for mechanically reinforcing said pin.

77. The electric storage battery of any of claims 66 - 76 wherein said battery has a capacity of at least 70% of the 0.2C capacity at rates up to and including 5C.

78. The electric storage battery of any of claims 66 - 76 wherein said battery has a capacity of at least 80% of the 0.2C capacity at rates up to and including 5C.

79. The electric storage battery of any of claims 66 - 76 wherein said battery has a capacity of 90% of the 0.2C capacity at rates up to and including 3C.

80. The electric storage battery of any of claims 66 - 76 wherein said battery has a capacity of 95% of the 0.2C capacity at rates up to and including 1C.

81. An electric storage battery including:

a case comprising a peripheral wall defining an interior volume and having an external width of less than 3 mm; and

an electrode assembly mounted in said interior volume, said electrode assembly including first and second opposite polarity electrode strips wound together to form a spiral roll.

82. The electric storage battery of claim 81 wherein said case has an external volume is less than 1 cm^3

83. The electric storage battery of 81 wherein said case has an external volume is less than 0.5 cm^3.

84. The electric storage battery of claim 81 wherein said case has an external volume is less than 0.1 cm^3.

85. The electric storage battery of any of claims 81 - 84 wherein said case is circularly cylindrical and said width is a diameter.

86. The electric storage battery of any of claims 81 - 85 wherein said case is hermetically sealed.

87. The electric storage battery of any of claims 81 - 86 wherein said battery is rechargeable.

88. The electric storage battery of any of claims 81 - 86 wherein said battery is a primary battery.

89. The electric storage battery of any of claims 81 - 88 wherein said battery is a lithium or lithium ion battery.

90. The electric storage battery of any of claims 81 - 89 wherein said electrode assembly further includes:

an electrically conductive elongate pin; and

wherein each electrode strip has inner and outer ends, wherein said first electrode strip is electrically coupled to said pin at said inner end.

91. The electric storage battery of claim 90 wherein said electrode assembly further includes a hollow elongate mandrel closely fitted around said pin for mechanically reinforcing said pin.

92. The electric storage battery of any of claims 81 - 91 wherein said battery has a capacity of at least 70% of the 0.2C capacity at rates up to and including 5C.

93. The electric storage battery of any of claims 81 - 91 wherein said battery has a capacity of at least 80% of the 0.2C capacity at rates up to and including 5C.

94. The electric storage battery of any of claims 81 - 91 wherein said battery has a capacity of 90% of the 0.2C capacity at rates up to and including 3C.

95. The electric storage battery of any of claims 81 - 91 wherein said battery has a capacity of 95% of the 0.2C capacity at rates up to and including 1C.

96. A rechargeable electric storage battery including:

a case comprising a peripheral wall defining an interior volume and an exterior volume of less than 1 cm^3; and

an electrode assembly mounted in said interior volume, said electrode assembly including first and second opposite polarity electrodes.

97. The rechargeable electric storage battery of claim 96 wherein said external volume is less than 0.5 cm^3.

98. The rechargeable electric storage battery of claim 96 wherein said external volume is less than 0.1 cm^3.

99. The rechargeable electric storage battery of any of claims 96 - 98 wherein said case is circularly cylindrical.

100. The rechargeable electric storage battery of any of claims 96 - 99 wherein said case has a diameter less than 3 mm.

101. The electric storage battery of any of claims 96 - 100 wherein said case is hermetically sealed.

102. The rechargeable electric storage battery of any of claims 96 - 101 wherein said battery is a lithium or lithium ion battery.

103. The rechargeable electric storage battery of any of claims 96 - 102 wherein said electrode assembly further includes:

an electrically conductive elongate pin; and

wherein each electrode strip has inner and outer ends, wherein said first electrode strip is electrically coupled to said pin at said inner end.

104. The rechargeable electric storage battery of claim 103 wherein said electrode assembly further includes a hollow elongate mandrel closely fitted around said pin for mechanically reinforcing said pin.

105. The rechargeable electric storage battery of any of claims 96 - 104 wherein said battery has a capacity of at least 70% of the 0.2C capacity at rates up to and including 5C.

106. The rechargeable electric storage battery of any of claims 96 - 104 wherein said battery has a capacity of at least 80% of the 0.2C capacity at rates up to and including 5C.

107. The rechargeable electric storage battery of any of claims 96 - 104 wherein said battery has a capacity of 90% of the 0.2C capacity at rates up to and including 3C.

108. The rechargeable electric storage battery of any of claims 96 - 104 wherein said battery has a capacity of 95% of the 0.2C capacity at rates up to and including 1C.

109. An electric storage battery including:

a case comprising a peripheral wall having a thickness of less than 0.25 mm and defining an interior volume; and

an electrode assembly mounted in said interior volume, said electrode assembly including first and second opposite polarity electrodes.

110. The electric storage battery of claim 109 wherein said thickness is less than 0.125 mm.

111. The electric storage battery of claim 109 wherein said thickness is less than 0.076 mm.

112. The electric storage battery of any of claims 109 - 111 wherein said external volume is less than 1 cm^3.

113. The electric storage battery of any of claims 109 - 112 wherein said external volume is less than 0.5 cm^3.

114. The electric storage battery of any of claims 109 - 113 wherein said external volume is less than 0.1 cm^3.

115. The electric storage battery of any of claims 109 - 114 wherein said case is circularly cylindrical.

116. The electric storage battery of any of claims 109 - 115 wherein said case has a diameter less than 3 mm.

117. The electric storage battery of any of claims 109 - 116 wherein said case is hermetically sealed.

118. The electric storage battery of any of claims 109 - 117 wherein said battery is a lithium or lithium ion battery.

119. The electric storage battery of any of claims 109 - 118 wherein said case comprises a titanium alloy.

120. The electric storage battery of any of claims 109 - 119 wherein said case comprises stainless steel.

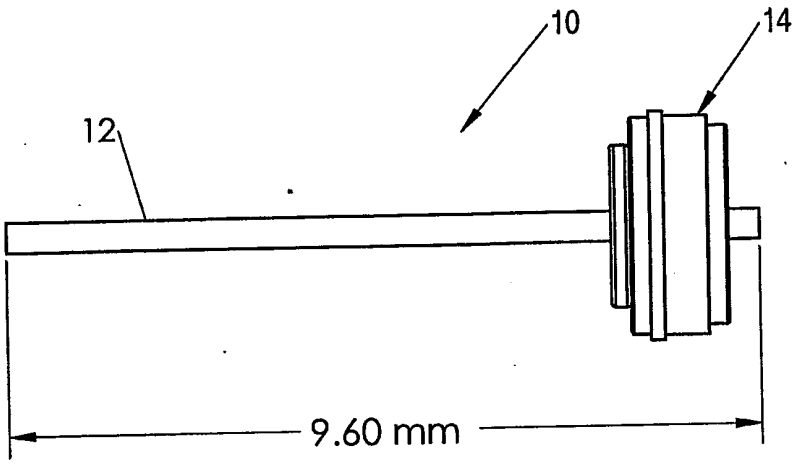

FIG. 1

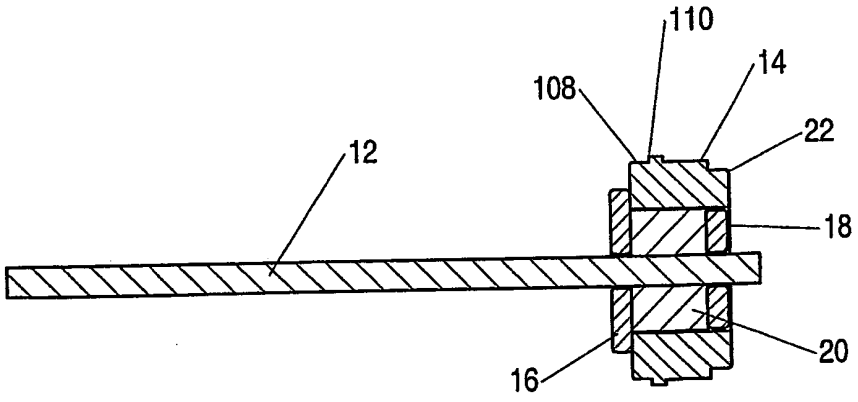

FIG. 2

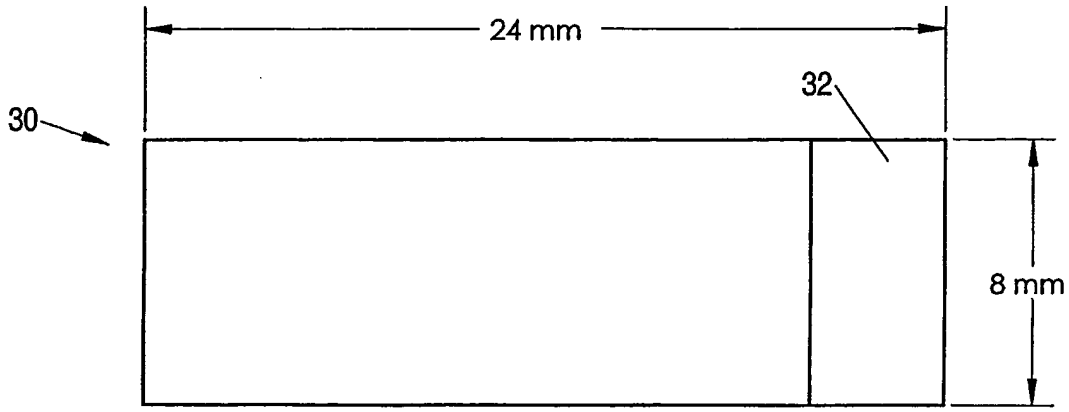

FIG. 3

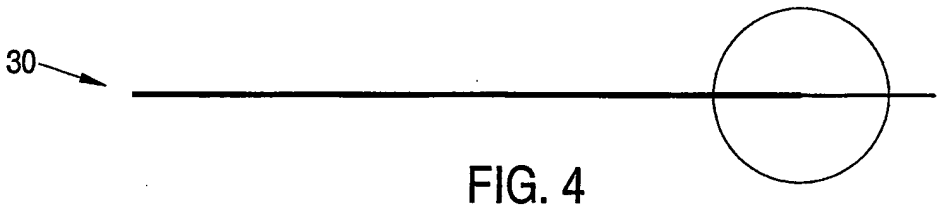

FIG. 4

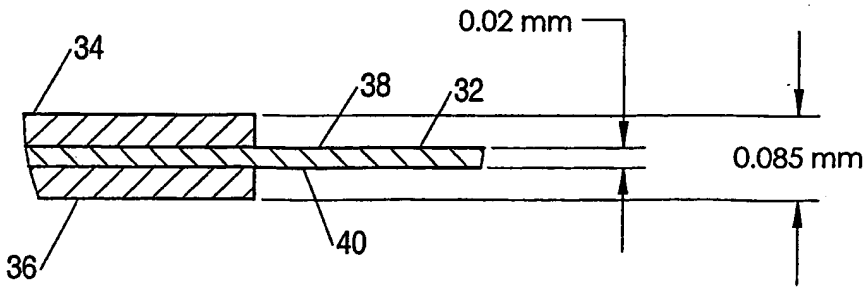

FIG. 5

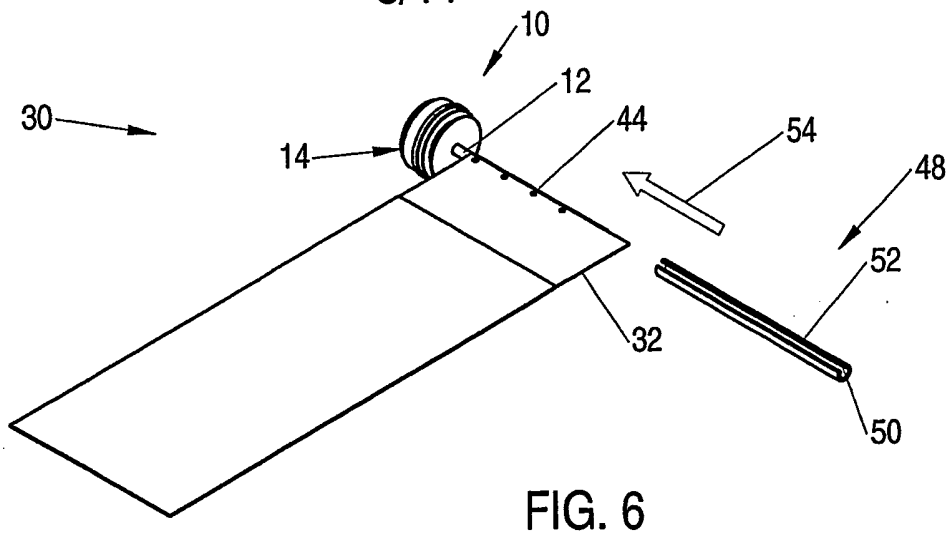

FIG. 6

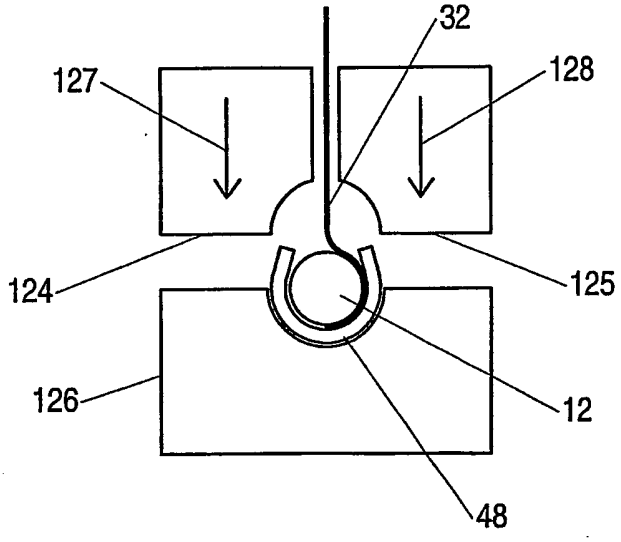

FIG. 7

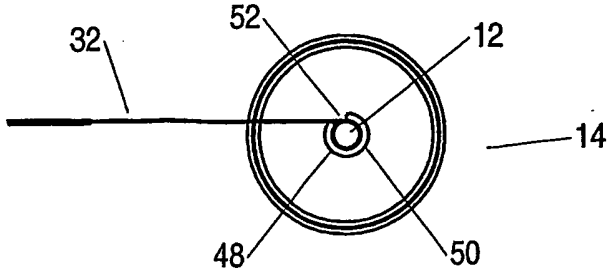

FIG. 8

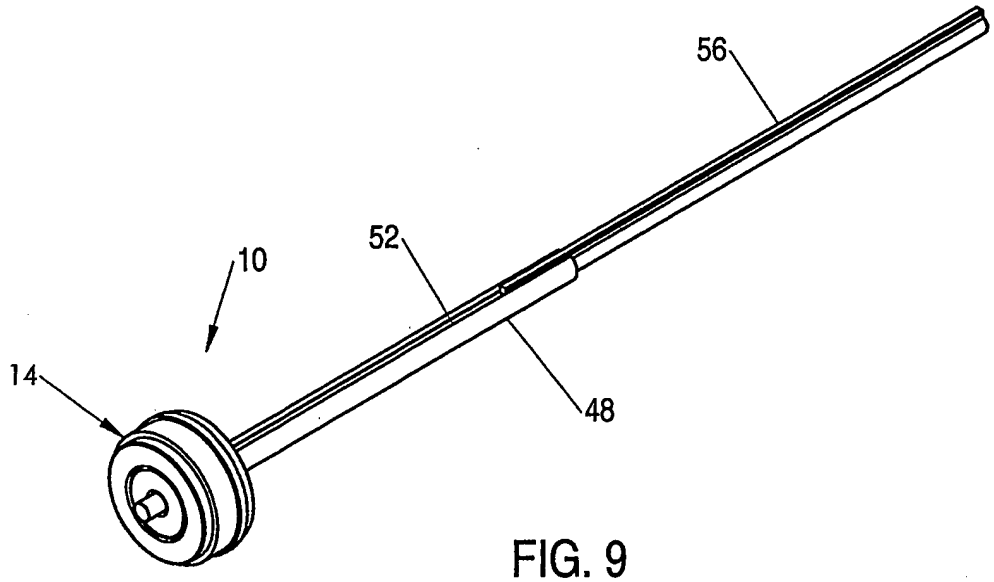

FIG. 9

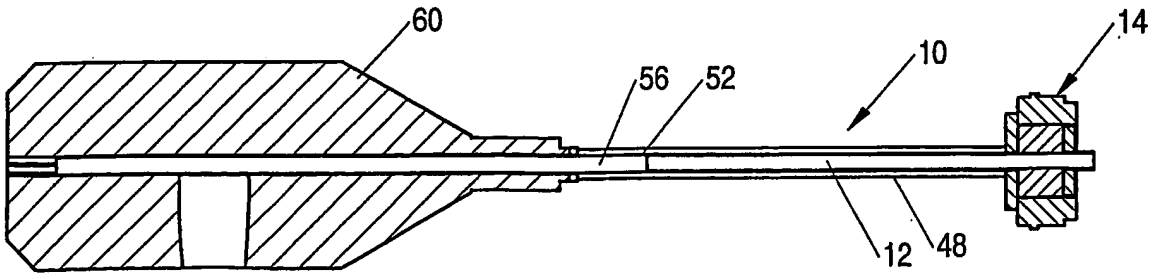

FIG. 10

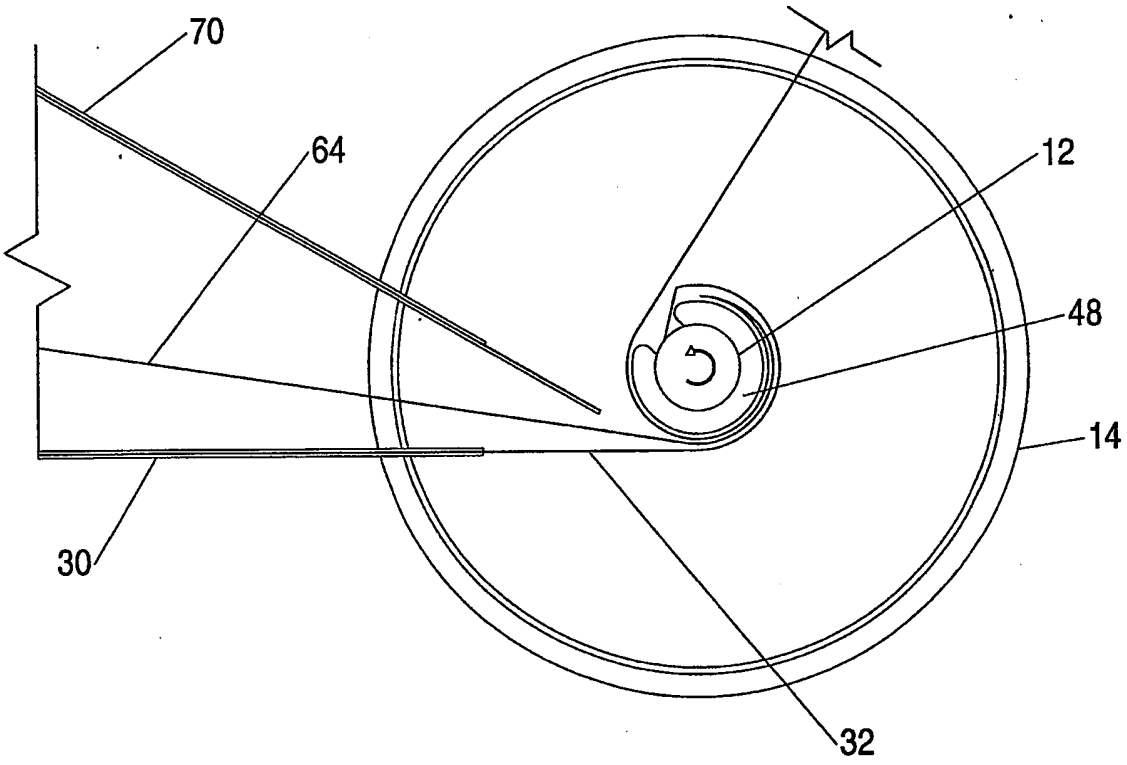

FIG. 11

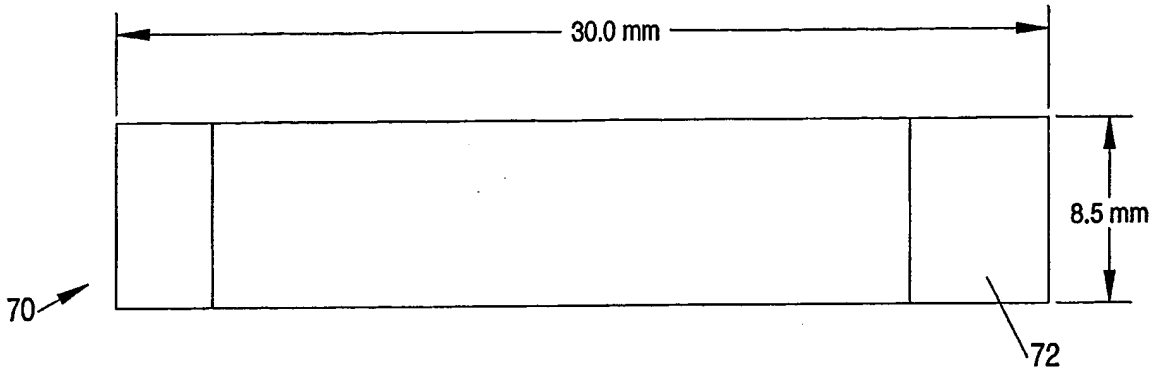

FIG. 12

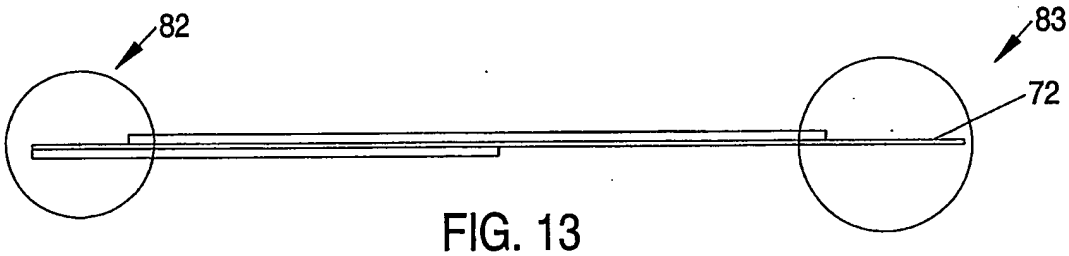

FIG. 13

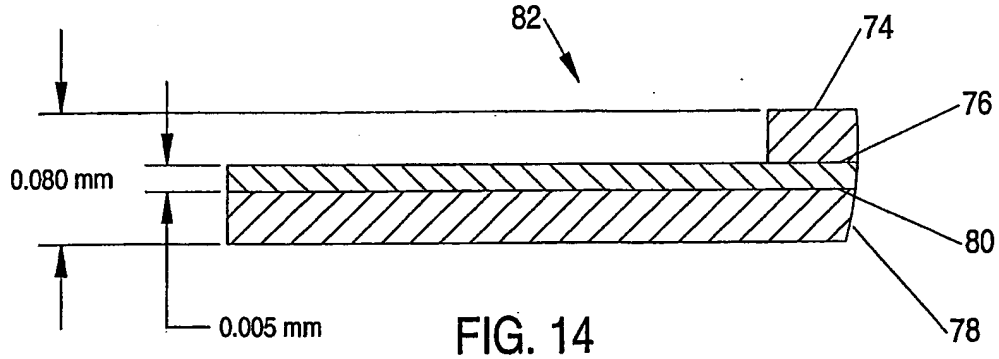

FIG. 14

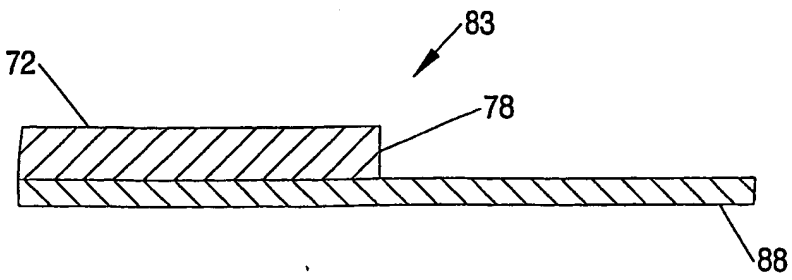

FIG. 15

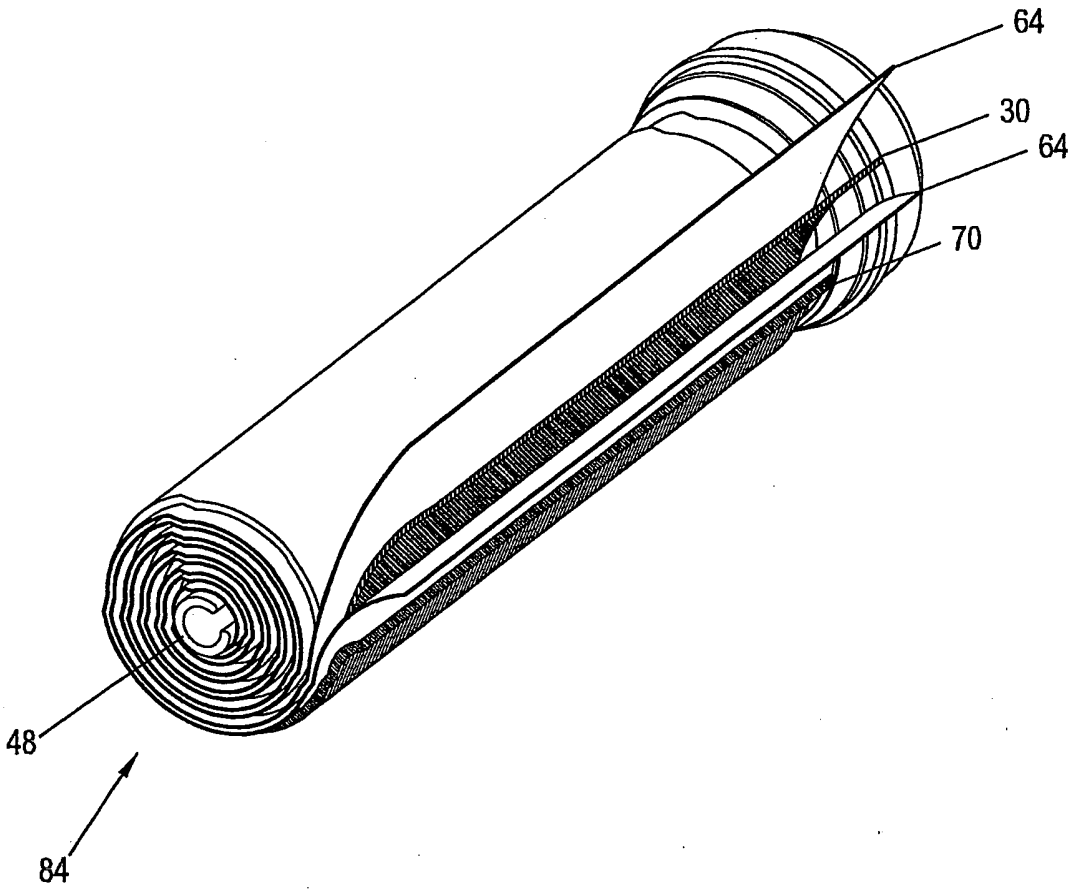

FIG. 16

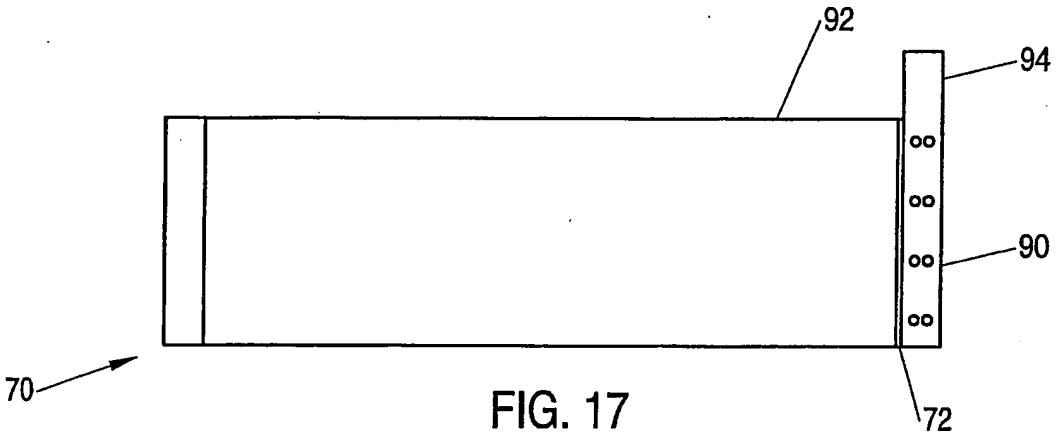

FIG. 17

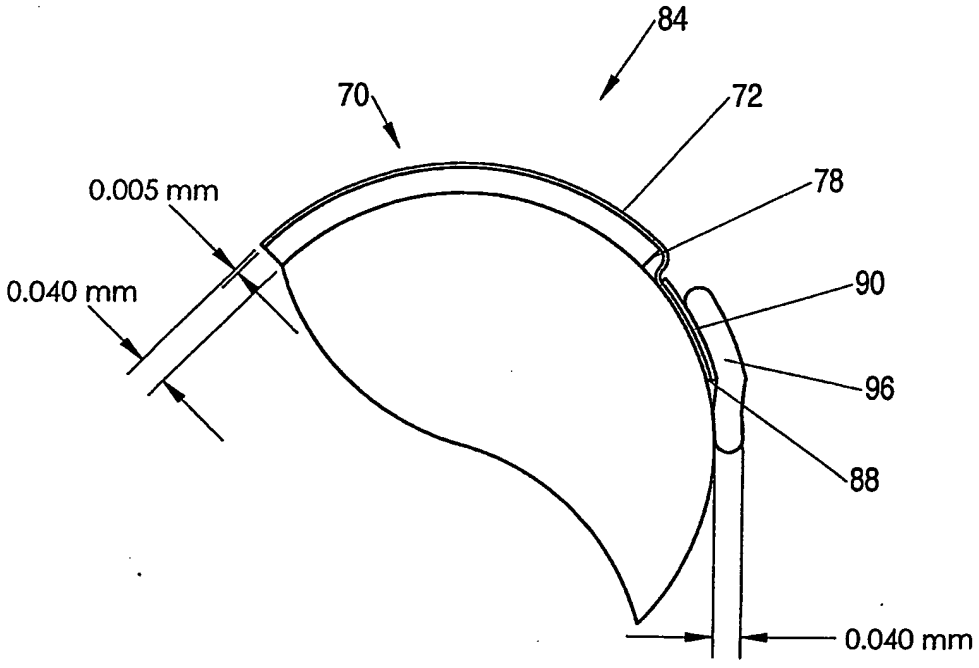

FIG. 18

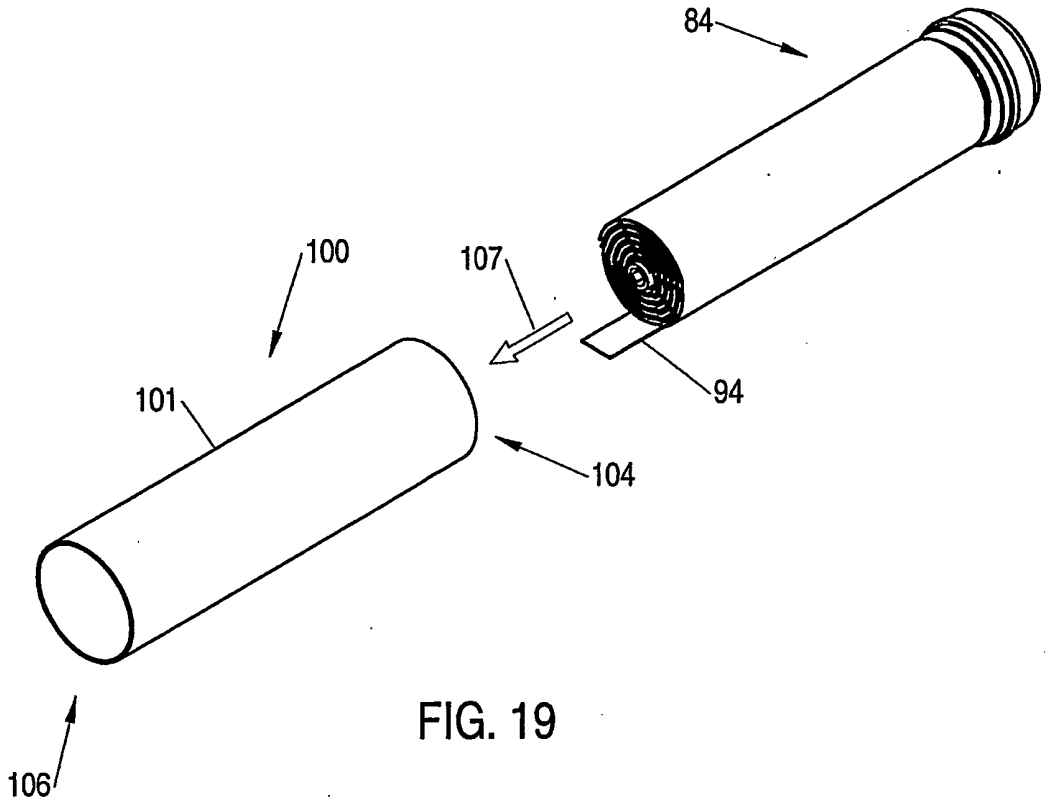

FIG. 19

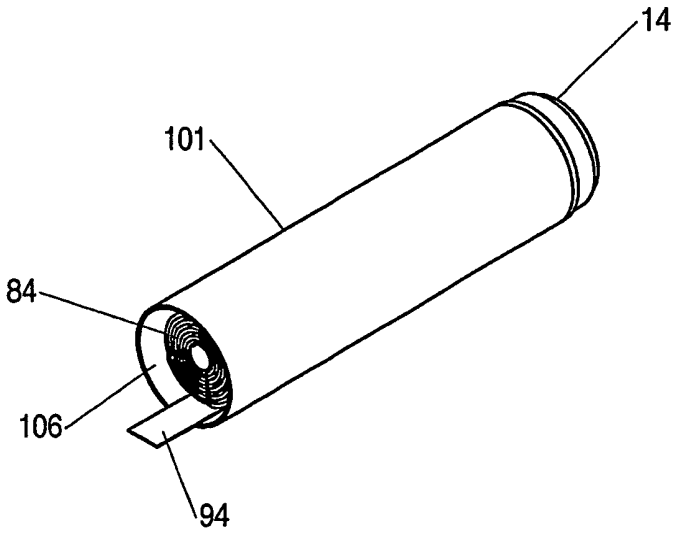

FIG. 20

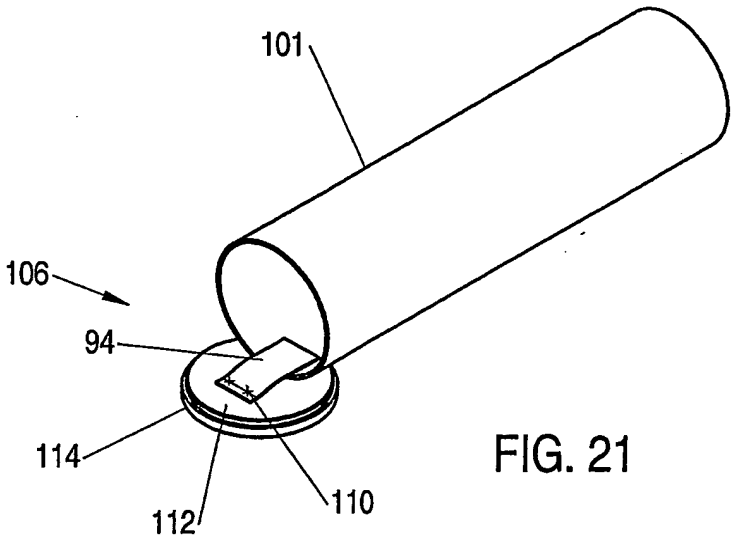

FIG. 21

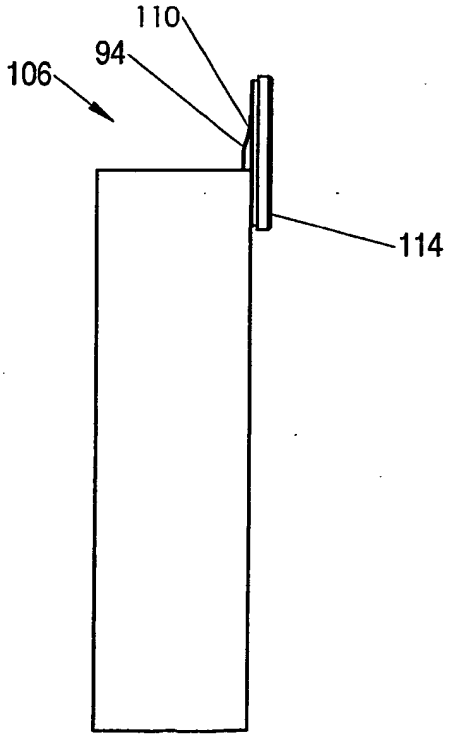

FIG. 22

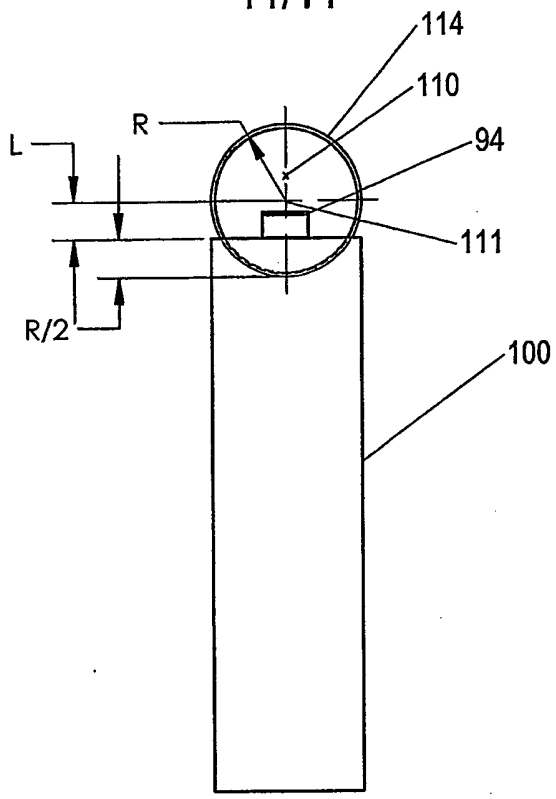

FIG. 23

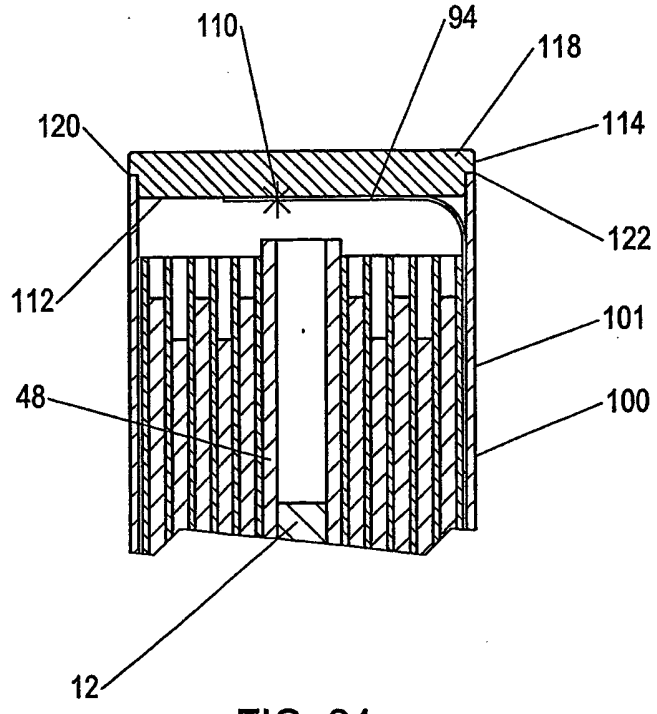

FIG. 24

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US03/01338

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : H01M 6/10
US CL : 429/94, 29/623.1
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 429/94, 29/623.1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
EAST

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	US 6,432,574 B1 (SUZUKI et al) 13 August 2002 (13.08.2002), column 4, lines 40-57; column 5, lines 17-21.	43-55,60-65
A	US 5,925,482 (YAMASHITA et al) 20 July 1999 (20.07.1999), column 10, line 63 to column 11, line 32, Figures 5 and 6.	1-42
A	US 6,132,898 (KAWAMURA et al) 17 October 2000 (17.10.2000), column 5, lines 13-57, Figures 3-5.	1-42
A	US 6,308,101 B1 (FALTYS et al) 23 October 2001 (23.10.2001), column 20, lines 62-64.	66-120

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
28 May 2003 (28.05.2003)

Date of mailing of the international search report
19 JUN 2003

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Form PCT/ISA/210 (second sheet) (July 1998)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US03/01338

Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claim Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claim Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claim Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
Please See Continuation Sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

PCT/US03/01338

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claims 1-9, drawn to an electric storage battery having a hollow elongate mandrel.

Group II, claims 10-27, drawn to an electric storage battery having an electrically conductive elongate pin having inner and outer ends and a reinforcing mandrel on the pin.

Group III, claims 28-32, drawn to an electrode assembly having at least one separator strip.

Group IV, claims 33-42, drawn to an electrode assembly having an electrically conductive elongate pin and a reinforcing mandrel on the pin.

Group V, claims 43-46, drawn to an electrode storage battery comprising a first end cap, a second end cap and a flexible conductive tab.

Group VI, claims 47-54, drawn to an electric storage battery comprising a first end cap, a second end cap, a flexible conductive tab and a fastening means between the second end cap and the tab.

Group VII, claims 55-57, drawn to an electric storage battery that requires no separate fill holes.

Group VIII, claims 58-59, drawn to an electrode storage battery that deposits electrolyte into the case through the second wall opening.

Group IX, claims 60-65, drawn to a hermetically sealable electric storage battery comprising a case having an open end.

Group X, claims 66-80, drawn to an electric storage battery comprising a case comprising a peripheral wall defining an interior volume and an exterior volume of less than 1 cm^3.

Group XI, claims 81-95, drawn to an electric storage battery comprising a case comprising a peripheral wall defining an interior volume and having an external width of less than 3 mm.

Group XII, claims 96-108, drawn to a rechargeable electric storage battery comprising a case comprising a peripheral wall defining an interior volume and an exterior volume of less than 1 cm^3.

Group XIII, claims 109-120, drawn to an electric storage battery comprising a case comprising a peripheral wall having a thickness of less than 0.25 mm and defining an interior volume.

The inventions listed as Groups I-XIII do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: Group I requires a hollow elongate mandrel, which is not required by other groups. Group II requires an electrically conductive elongate pin having inner and outer ends and a reinforcing mandrel on the pin, which are not required by other groups. Group III requires at least one separator strip, which is not required by other groups. Group IV requires an electrically conductive elongate pin and a reinforcing mandrel on the pin, which are not required by other groups. Group V requires a first end cap, a second end cap and a flexible conductive tab, which are not required by other groups. Group VI requires a first end cap, a second end cap, a flexible conductive tab and a fastening means between the second end cap and the tab, which are not required by other groups. Group VII requires no separate fill holes in the battery, which is not required by other groups. Group VIII requires to deposits electrolyte into the case through the second wall opening, which is not required by other groups. Group IX requires an open end in the battery, which is not required by other groups. Group X requires a case comprising a peripheral wall defining an interior volume and an exterior volume of less than 1 cm^3, which is not required by other groups. Group XI requires a case comprising a peripheral wall defining an interior volume and having an external width of less than 3 mm, which is not required by other groups. Group XII requires a case comprising a peripheral wall defining an interior volume and an exterior volume of less than 1 cm^3 in a rechargeable battery, which is not required by other groups. Group XIII requires a case comprising a peripheral wall having a thickness of less than 0.25 mm and defining an interior volume, which is not required by other groups.